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· Clinical Research ·

Effects of steep-axis incision on corneal curvature in one-handed phacoemulsification

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Abstract
● AIM: To examine the effects of one-handed phacoemulsification with steep-axis incision on corneal curvature and analyze surgically induced astigmatism (SIA) on the true net power, anterior and posterior corneal surfaces.

● METHODS: Patients with cataracts underwent one-handed phacoemulsification with a 2.4-mm steep-axis of clear corneal incision (CCI) based on true net power. CCI was created under the guidance of Verion. Central corneal thickness (CCT), keratometry readings of the true net power and anterior and posterior corneal surface were obtained using Pentacam. Biometry, such as axial length, anterior chamber depth (ACD) and white-to-white (WTW) were performed using Lenstar pre- and 3mo post-operatively.

● RESULTS: The study evaluated 68 eyes of 65 patients. The mean age was 65.93±9.40y; CCT was 529.21±37.40 μm; WTW was 11.59±0.35 mm. Regarding true net power, keratometric value at the flattest corneal meridian for the 3-mm central zone (Ks) was significantly decreased postoperatively (*P*=0.031). Keratometric value at the steepest corneal meridian for the 3-mm central zone (Kf) was increased postoperatively (*P*>0.05). Astigmatism of true net power was 1.21±0.56 D preoperatively and significantly decreased to 1.02±0.58 D postoperatively (*P*=0.021). On the anterior corneal surface, no significant difference in Ks and Kf was noted pre- versus postoperatively. Anterior corneal astigmatism was 1.08±0.51 D preoperatively and significantly decreased to 0.87±0.46 D postoperatively (*P*=0.002). On the posterior corneal surface, Ks and Kf were significantly increased postoperatively (all *P*<0.05), and posterior corneal astigmatism also increased (*P*=0.008). The SIA values of true net power and the anterior and posterior corneal surfaces at 3mo postoperatively were 1.26±0.63 D (range: 0.11 to 2.80 D), 1.05±0.54 D (range: 0.23 to 2.40 D), and 0.21±0.17 D (range: 0.01 to 0.07 D), respectively.

● CONCLUSION: One-handed phacoemulsification with steep-axis incision can effectively decrease astigmatism of true net power and anterior corneal astigmatism. In the same surgery, the difference in personal SIA potentially originated from a difference in personal corneal thickness and diameter, both CCT and WTW distance should always be measured preoperatively when planning steep-axis phacoemulsification.

● KEYWORDS: steep-axis; one-handed phacoemulsification; true net power; surgically induced astigmatism
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INTRODUCTION

Currently, cataract surgery has entered the era of refractive surgery, and the intraoperative correction of corneal astigmatism is a necessary requirement for refractive cataract surgery (RCS). Many methods are available to correct preexisting corneal astigmatism, such as single or paired opposite clear corneal incision (CCI) at the steepest meridian[1-2], limbal relaxing incision[3], and Toric intraocular lens (IOL) implantation[4]. Precise measurement of corneal astigmatism is crucial for RCS and other refractive surgical corrections. Conventional devices, such as keratometry, calculate corneal astigmatism [known as keratometric astigmatism (KA); the keratometric refractive index is typically 1.3375] only based on the anterior corneal planes[5]. Current Scheimpflug tomographers are based on the Scheimpflug principle and measure both the anterior and posterior corneal surfaces. The device calculates the true net power of the total cornea by adding sagittal curvature values of the anterior and posterior corneal surface and measures the total corneal astigmatism (TCA) by a ray tracing technique[6].

Previous studies have analyzed surgically induced astigmatism (SIA) based on steep-axis CCI of anterior corneal astigmatism (ACA) or KA in two-handed phacoemulsification[1]. The main purpose of our study was to examine the effects of steep-axis CCI (based on the steep meridian of true net power) on corneal curvature in one-handed phacoemulsification and to analyze the SIA on the true net power and anterior and posterior cornea surfaces.

SUBJECTS AND METHODS

Ethical Approval This study was performed in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Affiliated Hospital of Nantong University's Ethics Committee. All patients provided written informed consent after receiving a full explanation of the study.

Subjects This study consisted of patients with age-related cataract (ARC) who underwent one-handed phacoemulsification at the Department of Ophthalmology, Affiliated Hospital of Nantong University, Jiangsu, China, from January 2017 to September 2017. The Lens Opacities Classification System III (LOCS III) was used for cataract classification. Inclusion criteria included the following: 1) patients with ARC and regular astigmatism; 2) nuclear opalescence ≤3; 3) normal anterior segment and fundus examination; 4) no history of intraocular surgery or injury. Exclusion criteria included the following: 1) cataract other than ARC; 2) corneal scars, corneal opacities and other ocular disease that might affect visual outcomes.

Measurements All patients underwent a complete ophthalmologic measurement. Biometry, such as white-to-white (WTW), anterior chamber depth (ACD) and axial length, were performed using a Lenstar non-contact optical low-coherence reflectometer (LS900; Haag-Streit, Koniz, Switzerland). Central corneal thickness (CCT), keratometry readings of the true net power, anterior and posterior corneal surface were obtained using a Pentacam (70700, Oculus, Wetzlar, Germany). Anatomic landmarks of the eye were obtained using Verion (Alcon Laboratories, Inc., Fort Worth, TX, USA). The image was then transferred onto a USB drive inserted into the Verion Digital Marker monitor screen, which was used to guide the position of steep-axis CCI. The 2.4-mm CCI was selected for the steep axis, which was chosen according to the steepest corneal meridian of the true net power. The triangle representing the target incision appeared on both the microscope and monitor (Figure 1).

Surgical Technique All operations were performed by an experienced surgeon (Guan HJ). A 2.4-mm single-plane CCI was created at the steep meridian of true net power under the guidance of Verion. Central continuous curvilinear capsulorhexis (CCCC) was performed under the guidance of Version. After CCCC, hydrodissection and hydrodelineation were performed, and nuclear emulsification was performed using the one-handed technique[7]. All phacoemulsification was performed using the Centurion Vision System (Alcon, Fort Worth, America) in burst mode. The ultrasound and fluidic settings were as follows: bottle height, 105 cm; power, 60%; vacuum, 500 mm Hg; and aspiration flow, 32 mL/min. A foldable monofocal IOL (PY-60AD; HOYA, Tokyo, Japan) was implanted. At the end of the surgery, the CCI was hydrated.

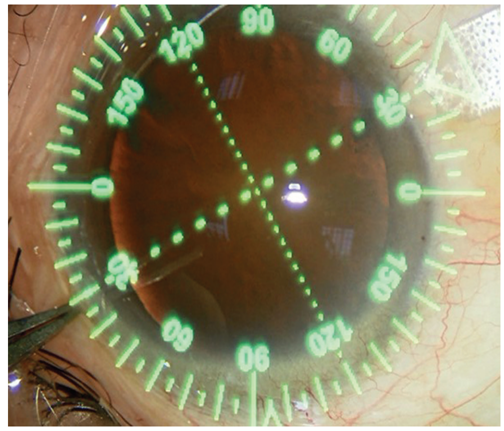

Figure 1 The steep-axis clear corneal incision was created at 30° under the guidance of Verion.

Data Analysis The true net power of the cornea and ACA were classified into three types according to the meridian of the maximal convergent power: within 90°±30° [with the rule (WTR)], within 0±30° [against the rule (ATR)], and within 30°-60° or 120°-150° [oblique (OBL)][8]. Given that the dioptric power of the posterior corneal surface was negative, we classified posterior corneal astigmatism (PCA) as WTR when the steep meridian was within 0±30° and as ATR when the steep meridian was within 90°±30°. We classified the remaining astigmatism as oblique astigmatism[9].

Vector Analysis SIA was analyzed by vector analysis according to the Alpins method[10]. $SIA= [A1^2+A2^2-2A1A2\times\cos2(\Phi1-\Phi2)]^{1/2}$ (A1 was the preoperative corneal astigmatism value; Φ1 was the preoperative corneal astigmatism axis; A2 was the postoperative astigmatism value; Φ2 was the preoperative corneal astigmatism axis).

Statistical Analysis Statistical analysis was performed using SPSS for Windows software (version 22, SPSS, Inc., America). The Chi-square test was used for comparison of the type of corneal astigmatism. The paired-samples *t*-test was used for the comparison of preoperative and postoperative data. The level of statistical significance was $P<0.05$.

RESULTS

Our study evaluated 68 eyes (37 right and 31 left) from 65 patients (42 females and 23 males). The mean age was 65.93±9.40y (range: 50 to 85y, 95%CI for the mean: 63.65 to

Table 1 Types of corneal astigmatism preoperatively and 3mo postoperatively *n* (%)

Astigmatism	Preoperative	Postoperative	*P*
True net power			0.221
With the rule	12 (26.00)	15 (22.06)	
Against the rule	40 (52.00)	30 (44.12)	
Oblique	16 (2.00)	23 (33.82)	
Anterior corneal surface			0.248
With the rule	15 (22.06)	23 (33.82)	
Against the rule	33 (48.53)	25 (36.76)	
Oblique	20 (29.41)	20 (29.41)	
Posterior corneal surface			0.804
With the rule	7 (10.29)	7 (0.29)	
Against the rule	57 (83.82)	55 (80.88)	
Oblique	4 (5.88)	6 (8.82)	

Table 2 Keratometric data and SIA of the true net power preoperatively and 3mo postoperatively

Parameters	Preoperative		Postoperative		*P*
	Mean±SD	95%CI	Mean±SD	95%CI	
Ks	43.97±1.58	43.59 to 44.36	43.76±1.33	43.43 to 44.08	0.031
Kf	42.72±1.54	42.72 to 1.54	42.73±1.38	42.40 to 43.07	0.825
Astigmatism	1.21±0.56	1.08 to 1.35	1.02±0.58	0.88 to 1.16	0.021
J_0	-0.29±0.51	-0.41 to -0.17	-0.14±0.41	-0.24 to -0.44	0.005
J_{45}	-0.19±0.26	0.13 to 0.26	-0.12±0.38	-0.21 to -0.03	0.000
SIA	-	-	1.26±0.63	1.11 to 1.41	-

Ks: Keratometric value at the flattest corneal meridian for the 3-mm central zone; Kf: Keratometric value at the steepest corneal meridian for the 3-mm central zone; J_0: Power vectors were computed at axis 0 according to the Jackson coefficient orthogonal coordinate system; J_{45}: Power vectors were computed at axis 45 according to the Jackson coefficient orthogonal coordinate system; SIA: Surgically induced astigmatism.

68.20y). The axial length was 24.09±2.40 mm (range: 20.97 to 30.92 mm, 95%CI for the mean: 23.51 to 24.61 mm). The CCT was 529.21±37.40 μm (range: 449 to 619 μm, 95%CI for the mean: 520.15 to 538.26 μm). The WTW was 11.59±0.35 mm (range: 10.86 to 12.32 mm, 95%CI for the mean: 11.51 to 11.67 mm). Preoperatively, the mean magnitude of true net power, ACA and PCA were 1.21×82.78°, 1.08×81.74° and -0.25×86.78°, respectively. Postoperatively, the mean magnitude of true net power, ACA and PCA were 1.02×95.1°, 0.87×93.18° and -0.31×79.21°, respectively.

Table 1 presents the types of corneal astigmatism preoperatively and at 3mo postoperatively, and no statistically significant difference was noted in the composition of astigmatism type on true net power and the anterior and posterior corneal surface preoperatively versus postoperatively (all $P>0.05$).

Tables 2-4 present the keratometric data [keratometric value at the flattest corneal meridian for the 3-mm central zone (Ks), keratometric value at the steepest corneal meridian for the 3-mm central zone (Kf), astigmatism, power vectors were computed at axis 0 according to the Jackson coefficient orthogonal coordinate system (J_0), power vectors were computed at axis 45 according to the Jackson coefficient orthogonal coordinate system (J_{45})] and SIA of the true net power, anterior and posterior corneal surface preoperatively and at 3mo postoperatively.

Ks of true net power was significantly decreased at 3mo postoperatively (P=0.031). Kf of true net power was increased at 3mo postoperatively, but no significant difference was noted (P=0.825). Astigmatism of true net power was 1.21±0.56 D preoperatively and significantly decreased to 1.02±0.58 D at 3mo postoperatively (P=0.021). J_0 and J_{45} of true net power exhibited significant differences preoperatively versus postoperatively (all $P<0.05$).

No significant difference in Ks and Kf of the anterior corneal surface was noted preoperatively and postoperatively (all $P>0.05$). ACA was 1.08±0.51 D preoperatively and significantly decreased to 0.87±0.46 D at 3mo postoperatively (P=0.002). J_0 and J_{45} of the anterior corneal surface exhibited significant differences between preoperative and 3-month postoperative values (all $P<0.005$).

Ks and Kf of the posterior corneal surface were significantly increased at 3mo postoperatively (all $P<0.05$), and PCA was also increased (P=0.008). J_{45} of the posterior corneal surface exhibited significant differences between preoperative and postoperative values (P=0.012).

The SIA values of true net power and the anterior and posterior

Table 3 Keratometric data and SIA of the anterior corneal surface preoperatively and 3mo postoperatively

Parameters	Preoperative		Postoperative		P
	Mean±SD	95%CI	Mean±SD	95%CI	
Ks	45.15±1.51	44.79 to 45.52	43.04±1.33	44.72 to 45.36	0.095
Kf	44.07±1.47	43.72 to 44.43	44.17±1.37	43.88 to 44.50	0.203
Astigmatism	1.08±0.51	0.96 to 1.20	0.87±0.46	0.76 to 0.98	0.002
J_0	-0.16±0.49	-0.28 to -0.09	0.03±0.37	-0.11 to -0.06	0.011
J_{45}	0.18±0.24	0.12 to 0.24	-0.04±0.32	-0.12 to 0.03	0.000
SIA	-	-	1.05±0.54	0.92 to 1.19	-

Ks: Keratometric value at the flattest corneal meridian for the 3-mm central zone; Kf: Keratometric value at the steepest corneal meridian for the 3-mm central zone; J_0: Power vectors were computed at axis 0 according to the Jackson coefficient orthogonal coordinate system; J_{45}: Power vectors were computed at axis 45 according to the Jackson coefficient orthogonal coordinate system; SIA: Surgically induced astigmatism.

Table 4 Keratometric data and SIA of the posterior corneal surface preoperatively and 3mo postoperatively

Parameters	Preoperative		Postoperative		P
	Mean±SD	95%CI	Mean±SD	95%CI	
Ks	-6.55±0.27	-6.61 to -6.65	-6.65±0.28	-6.72 to -6.58	0.000
Kf	-6.59±0.30	-6.48 to -5.71	-6.63±0.23	-6.39 to -6.72	0.000
Astigmatism	-0.25±0.14	-0.29 to -0.22	-0.31±0.18	-0.35 to -0.26	0.008
J_0	-0.09±0.10	-0.06 to -0.11	-0.10±0.12	-0.13 to -0.08	0.180
J_{45}	-0.01±0.06	-0.02 to 0.01	-0.04±0.07	-0.05 to -0.01	0.012
SIA	-	-	0.21±0.17	0.17 to 0.25	-

Ks: Keratometric value at the flattest corneal meridian for the 3-mm central zone; Kf: Keratometric value at the steepest corneal meridian for the 3-mm central zone; J_0: Power vectors were computed at axis 0 according to the Jackson coefficient orthogonal coordinate system; J_{45}: Power vectors were computed at axis 45 according to the Jackson coefficient orthogonal coordinate system; SIA: Surgically induced astigmatism.

corneal surfaces at 3mo postoperatively were 1.26±0.63 D (range: 0.11 to 2.80 D, 95%CI for the mean: 1.11 to 1.41 D), 1.05±0.54 D (range: 0.23 to 2.40 D, 95%CI for the mean: 0.92 to 1.19 D), and 0.21±0.17 D (range: 0.01 to 0.07 D, 95%CI for the mean: 0.17 to 0.25 D), respectively. SIA values of true net power and anterior and posterior corneal surfaces greater than 0.5 D were noted in 60 eyes (88.23%), 55 eyes (80.88%) and 4 eyes (5.88%), respectively.

DISCUSSION

Correcting corneal astigmatism is one of the main goals during modern RCS. In previous practice, cataract surgeons typically paid more attention to ACA or KA because instruments to measure PCA or TCA were not commercially available. In recent years, people have become increasingly aware of the importance of total corneal curvature or true net power in RCS. The main purpose of our study was to examine the effects of one-handed phacoemulsification on corneal curvature and analyze the SIA of the true net power and the anterior and posterior cornea surfaces.

Improvements in ophthalmic instruments and microsurgical techniques have propelled CCI into the current trend of phacoemulsification[11]. In RCS, CCI at the steepest meridian is the simplest and most commonly used surgical procedure for correcting preexisting astigmatism of the cornea. Previous studies hypothesized that CCI at the steep axis could steepen the flat meridian[12]. In our study, Ks of true net power significantly decreased at 3mo postoperatively (P=0.031). Ks of the anterior corneal surface was decreased at 3mo postoperatively, but no significant difference was observed (P=0.095). This result is likely attributed to the fact that the steep median of the anterior corneal surface is close to the true net power but not completely identical, and our steep-axis CCI was based on the steep meridian of true net power. Borasion *et al*[13] reported that corneal astigmatism was 1.18±0.67 D preoperatively and 0.97±0.54 D postoperatively in the steep-axis CCI group, and the difference was statistically significant (P=0.03). In our study, astigmatism of true net power and ACA were significantly decreased at 3mo postoperatively (P<0.005). But PCA was significantly increased at 3mo postoperatively (P=0.008). This result is attributed to the fact that the steep median of the posterior corneal surface is different to the true net power in our study.

The SIA is an integral component of refractive surgery, and personalized SIA power has been advocated in the planning of cataract surgery. SIA is influenced by the incision numbers, size (width and length), configuration (1-step, 2-step, and 3-step) and location (clear corneal on-axis and temporal incisions)[11,14-18]. Cavallini *et al*[19] reported a mean SIA value of 0.72 D after coaxial phacoemulsification with a 2.2-mm CCI. Kawahara *et al*[14] reported that the mean SIA was

0.40±0.28 D and 0.39±0.25 D respectively in the one-handed and two-handed technique with a 2.4-mm transconjunctival single-plane sclerocorneal incision. Koç *et al*[20] reported a mean SIA value of 0.85±0.42 D with a 2.8-mm CCI and two 1-mm paracentesis 90° from the main port. Nemeth *et al*[1] reported that the SIA on the anterior surface was 0.49±0.29 D and SIA on the posteriorsurfac surface was 0.32±0.29 D after phacoemulsification with a 2.8-mm steep-axis CCI, and a 1.2-mm side port incisions was made 60° left of the main incision. Xu *et al*[21] reported that the mean SIA was 0.60±0.24 D in the temporal CCI group and 0.57±0.27 D in the steep-axis CCI group (P=0.84) with a 3.2-mm CCI. In our previous study, 3mo after one-handed phacoemulsification, the SIA on the anterior surface was 0.75±0.44 D. The SIA on the posterior surface was 0.22±0.14 D with a 2.4-mm single-plane CCI created at 135° position[11]. In this study, the SIA values of the true net power and anterior and posterior corneal surfaces at 3mo postoperatively were 1.26±0.63, 1.05±0.54, and 0.21±0.17 D, respectively. SIA of the anterior corneal surface was slightly increased compared with one-handed phacoemulsification with the same CCI created at 135°. SIA values of true net power and anterior and posterior corneal surfaces greater than 0.5 D were noted in 60 eyes (88.23%), 55 eyes (80.88%) and 4 eyes (5.88%), respectively. In our study, SIA was slightly higher than in previous studies.

The corneal thickness and radius also affect corneal astigmatism. Woo and Lee[22] reported that CCT was negatively correlated with the value of SIA. In his study, CCI was 537±30 μm, and SIA was approximately 0.6 D with a 2.7-mm CCI. Theodoulidou *et al*[23] reported that SIA was 0.77±0.43 D in group A (WTW≤11.6 mm), 0.69±0.34 D in group B (WTW: 11.7 to 11.9 mm), 0.62±0.36 D in group C (WTW: 12.0 to 12.2 mm), and 0.49±0.27 D in group D (WTW≥12.3 mm) with a 3.0-mm 3-step CCI. In our study, the CCT was 529.21±37.40 μm (range: 449 to 619 μm). The WTW was 11.59±0.35 mm (range: 10.86 to 12.32 mm). The SIA values of true net power and the anterior and posterior corneal surfaces at 3mo postoperatively were 1.26±0.63 D (range: 0.11 to 2.80 D), 1.05±0.54 D (range: 0.23 to 2.40 D), and 0.21±0.17 D (range: 0.01 to 0.07 D), respectively. Our CCT was thinner than Woo and Lee[22] and WTW was shorter than Theodoulidou *et al*[23]. This may be the reason why our SIA is larger than previous study. In the same surgery, the difference in personal SIA potentially originated from a difference in personal CCT or WTW.

Toric IOLs are another preferred solution to correct the preoperative corneal astigmatism during cataract surgery. We need to input steep K, steep axis, flat K, flat axis, SIA, incision location and other parameters using an online calculator. Personal CCT and WTW would influence his SIA thus influence calculating the type and axes of Toric IOLs. We often need to input the position of the main incision and ignore the position of the side incision when calculating the type and axes of Toric IOLs using the online calculator. Kawahara *et al*[14] found that there was no significant difference in SIA between the one-handed and two-handed group, but the corneal side port had a rotating effect on the axis of astigmatism which means corneal side incision would influence the calculation of axes of Toric IOLs. In addition, Xu *et al*[21] reported that compared with the temporal CCI, steep-axis CCI could improve the accuracy of Toric lens implantation and the ability to correct astigmatism. Combined with the above Kawahara *et al*[14] and Xu *et al*[21] two points, when we want to correct corneal astigmatism with Toric IOLs, we may be more inclined to performed steep-axis one-handed phacoemulsification without corneal side incision. Due to the limitation of the instrument (Pentacam, 70700, Oculus, Wetzlar, Germany), we must replace the total corneal curvature with true net power. Recently, some instruments obtained total corneal curvature by ray tracing calculation. Given that the anterior and posterior surfaces' principal planes are slightly different, total corneal curvature measured by ray tracing technique is more realistic than true net power[24].

In conclusion, our results indicate that one-handed phacoemulsification with steep-axis incision can effectively decrease the astigmatism of true net power and ACA. The CCT and WTW distance should always be measured preoperatively when planning steep-axis CCI or Toric IOL implantation. Further studies are needed to evaluate the effectiveness and accuracy of the one-handed technique combined with Toric lens implantation.

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